PRELIMINARY REPORT ON THE MEANING OF CARDIO-PNEUMATIC IMPULSES AND ON THE MODIFICATIONS OF THESE IMPULSES IN DISEASE.[1]

PRELIMINARY REMARKS.

A SLIGHT sound, corresponding to each heart beat, can be heard in the breath of some persons after they have taken violent exercise, or when they are under the influence of some emotions. My attention was attracted to that fact during the winter 1880-81 by one of my fellow-students in Edinburgh, who had noticed the phenomenon in himself, and thought it a sign of disease. It seemed to me, however, that the sound was produced by the rushing of air from the trachea into the pharynx, and *vice versâ*, through the narrow glottis, and that this motion was due to the contraction of the heart. I therefore attempted to find the conditions under which the sound was produced, and after finding them I got a number of persons to repeat the experiment, and satisfied myself that the phenomenon was a purely physiological one. It then occurred to me that if these impulses could be recorded, one might by their means obtain some useful information regarding the state of the thoracic contents. I communicated my results to Dr. Anderson Stuart, then Demonstrator of Physiology in Edinburgh (now Professor of Physiology in Sydney), who informed me that he had, during the same winter, observed the same facts in some dogs after the operation for tracheotomy. We made together some experiments, but on hearing from Professor Rutherford that this subject had been already worked out by Ceradini and Landois, we allowed the question to drop.[2]

On reconsidering the matter I, however, have come to the conclusion that these observers had not realised fully the meaning and the practical bearing of the phenomenon. It was with the object of getting some apparatus made for the purpose of overcoming the difficulties experienced in recording the impulses that I applied for a grant from the British Medical Association.

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[1] I hoped to have been able to give a series of tracings obtained from persons suffering from various chest troubles (chiefly pulmonary and cardiac), but not being able to do this yet by means of one method only, I have thought it advisable to defer this part of my investigation until comparable results could be obtained.

[2] Beaunis (*Physiologie Humaine*, p. 994, 1881) says that Voit and Lesser were the first to observe the phenomenon.

I. Nature of the Research.

My investigations can be subdivided into three parts:—

1. A study of the best methods for observing and recording the phenomenon in question.
2. A study of the meaning of the phenomenon itself.
3. A study of its variations under the influence of various physiological and pathological factors.

I am able to give at the present time definite results regarding the first two sections, but I will not attempt to deal at any length with the third, my results being so far insufficient to warrant any definite statement.

II. Methods.

The special conditions under which the cardio-pneumatic impulses are produced and transmitted to the cavity of the mouth have to be well understood before one can fully realise the importance of the selection of a method.

Each contraction of the heart causes, not only a considerable displacement of blood, but also a great alteration in the shape of the organ, and at the same time the thoracic wall is slightly thrown forward.

The heart being surrounded in almost every direction by the elastic pulmonary tissue, the alveoli of which are full of air and communicate more or less directly with the main bronchi, any alteration of shape of the heart will cause displacement of air, which will produce movements or waves in the air passages. These impulses will travel along these passages with considerable rapidity. Marey has shown that such waves travel along narrow tubes at the rate of 280 metres per second. The air passages are not uniform in size, but, with the exception of the terminal ones, have, on an average, a larger diameter than the tubes with which Marey experimented (this diameter was about 4 millimetres). It is therefore probable—in fact, practically certain—that the rate of transmission of the impulses from the neighbourhood of the heart to the opening of the mouth must have been much quicker than that of the 'pulse wave from the heart to the arteries of the neck, or even of most of those of the lungs.

This wave, although bulky and moving with considerable velocity, is under low pressure. To attempt to record such a wave by means of an ordinary mercury, or even water, manometer is practically impossible, owing to the resistance offered by tubes of suitable diameter to the flow of the liquid, and also owing to the slight momentum of the air communicating the impulse, which momentum is incapable of overcoming the inertia of the fluid contained in the the tube. This difficulty led me to have recourse to various forms of gas manometers, among which Marey's tambours and Koenig's manometric flames may be considered as the most convenient, and I succeeded in demonstrating the cardio-pneumatic impulses by these instruments. Most of them have had, however, to be more or less modified.

I have met with greater difficulty when attempting to record my results permanently, but have already succeeded in a way which leaves me no doubt as to the possibility of obtaining practical results applicable to diagnosis. I will now enumerate those methods which have proved useful, and explain the modifications which have been rendered necessary by the nature of the experiments.

1. Marey's tambours give very good results after the subject experimented upon has learnt to fix his chest walls and diaphragm, to stop breathing, and at the same time to keep the glottis widely open. This method has been used by Landois and François-Frank, both of whom have obtained tolerably good curves, those of the latter observer being very similar to mine. Both these observers, however, have failed, to my mind, to understand the conditions under which these impulses are produced, but I will refer to this later on. I have been obliged to have a special mouthpiece made by which the pressure of the air during respiration can be regulated. By causing people to breathe under pressure through a small opening, it becomes possible to receive the cardio-pneumatic impulses by means of a tambour during the act of respiration. In this way, persons who cannot learn to steady their chest walls and open their glottis without breathing can be made to give tolerably good tracings. The arrangement of this mouthpiece and of the recording apparatus will be best understood by the adjoining diagram (Fig. 1).

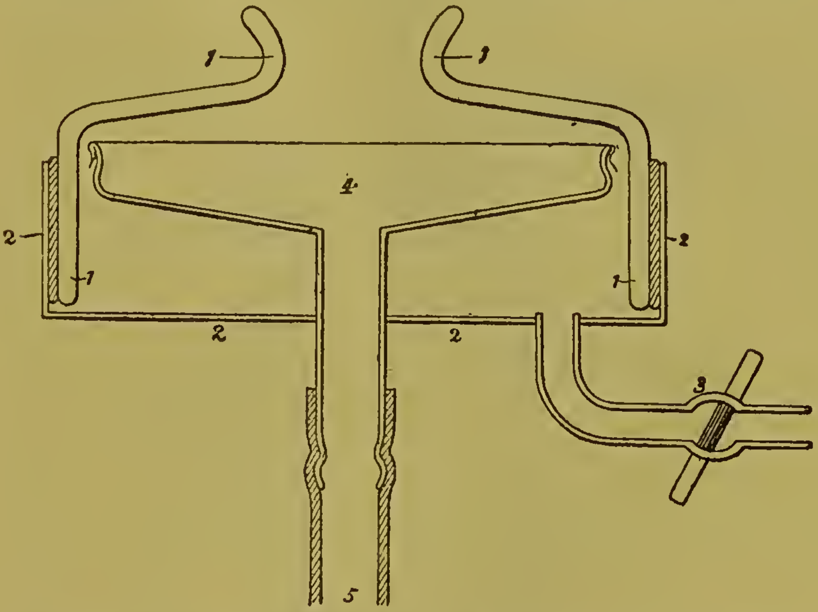

Fig. 1.—Mouthpiece constructed for the purpose of this Investigation. — 1. Glass mouthpiece with large aperture. 2. Brass capsule into which the glass mouthpiece fits tightly (the glass part of the apparatus can, however, be easily removed and replaced by another). 3. Tube through which respiration is effected when the mouthpiece is used; by turning the stopcock more or less inspiration and expiration may be rendered more or less difficult, and the air of the capsule may be put under positive or negative pressure. 4. Tambour with a thin loose india-rubber membrane. 5. India-rubber tube connecting this part of the apparatus with the recording part.

2. Koenig's manometric flames have not yielded very good results, probably owing to the small size of the openings and the tension of the elastic membrane in the apparatus de-

signed for the analysis of sounds which I had at my disposal. Landois speaks of having used a similar system.

In order to improve this method, I replaced the india-rubber membrane by a thin layer of water, used very large transmission tubes, regulated the size of the gas inlet and outlet, and obtained an apparatus by which the slightest motion of a gas, even under very low pressure, became manifest by very extensive flame oscillations. This apparatus is shown in the second diagram (Fig. 2).

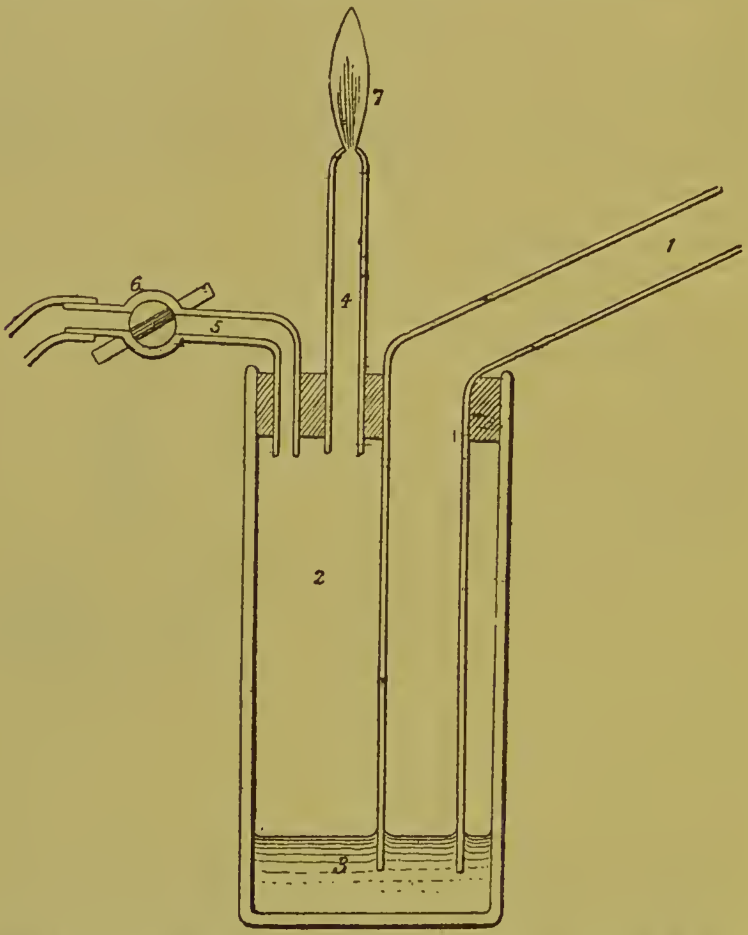

Fig. 2.—Manometric Flame Appparatus constructed for the purpose of this Investigation.—1. Tube connecting the apparatus with the buccal cavity or the mouthpiece. 2. Gas reservoir. 3. Water just occluding the lower end of the tube 1. 4. Burner with a small opening. 5. Tube bringing the gas into the reservoir 2. 6. Stopcock regulating the gas supply. 7. Flame.

The use of water being, however, inconvenient, I had another apparatus constructed without any interposed membrane or fluid, and which has given me very satisfactory results, as can be judged by the fact that even the pulse of the tip of the little finger can be clearly demonstrated when the capillaries of the skin are dilated by gentle heat or the use of alcohol (Fig. 3).

I know nothing surpassing the sensibility of these flames, but they are inconvenient when it is wanted to record their mo-

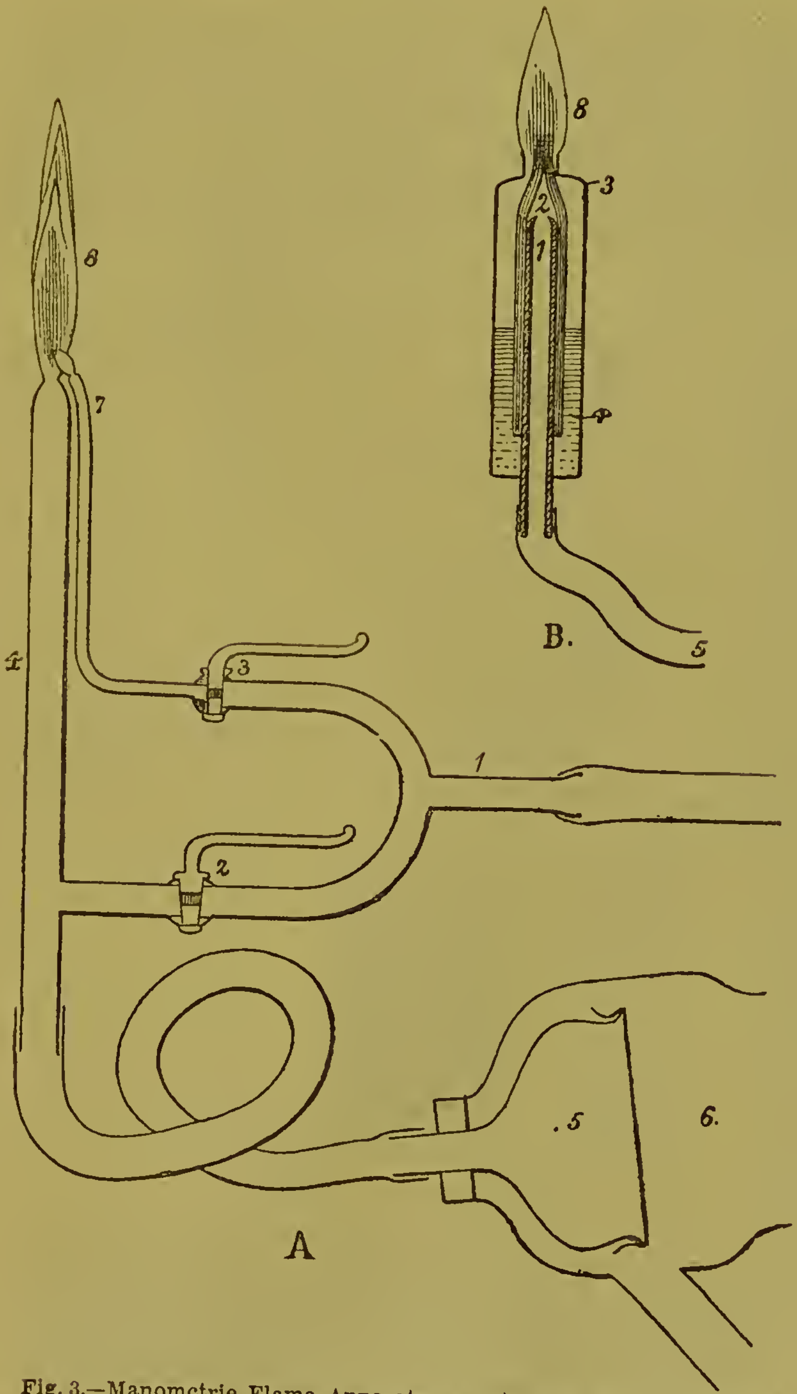

Fig. 3.—Manometric Flame Apparatus constructed for the purposes of this Investigation.—A. Gas apparatus. B. Oil apparatus. A.: 1. Gas supply. 2. Stopcock regulating the gas supply to the manometric tube. 3. Stopcock regulating the gas supply to the small side burner 7. 4. Manometric tube directly continuous with the wide india-rubber tube connecting the apparatus with the small tambour 5. This tambour is covered with a loose membrane, and can be directly applied to any part of the body or fixed in a mouthpiece 6. B.: 1. Manometric tube in the middle of the wick. 2. The wick. 3. The outer case containing the oil 4. 5. The tube connecting the apparatus with the mouthpiece. 8. The flame.

tion in any other place than a well-fitted physiological laboratory. Cyanogen flames cannot be used freely without serious inconvenience. I have also been obliged to discard several other devices on one ground or another. I have still at least one method which may prove generally applicable, but it is as yet too early to speak of it.

3. The difficulties connected with the flames caused me to revert to the other manometric methods, that is, I tried to use opaque columns of fluids moving in tubes; but, in order

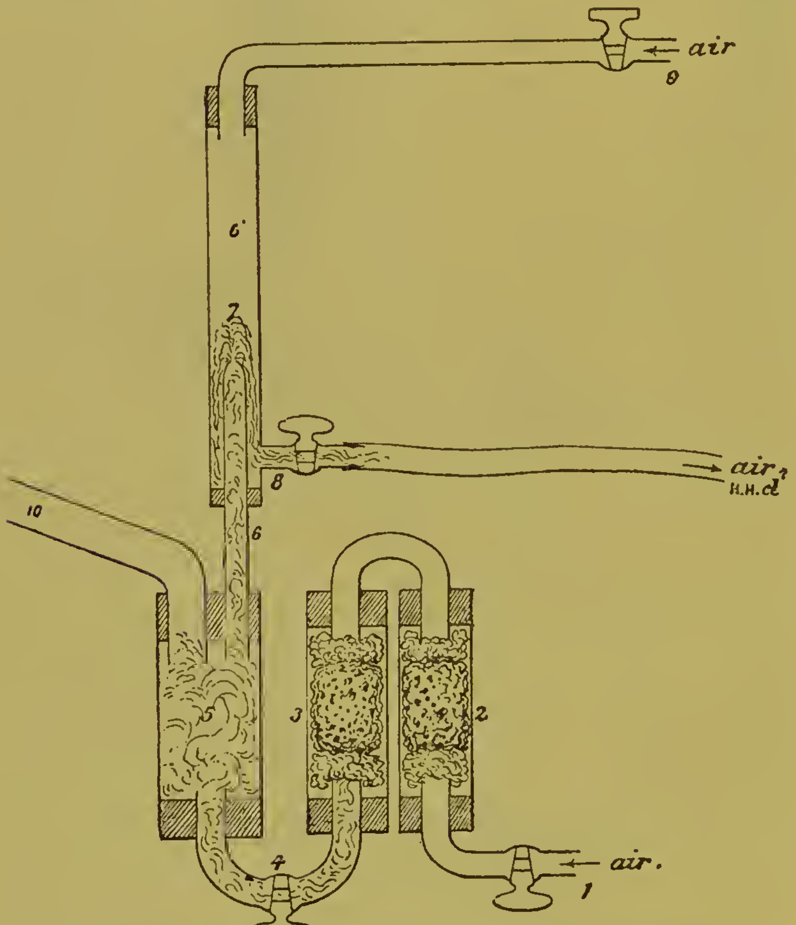

Fig. 4.—Vapour Manometer constructed for the purposes of this Investigation.—1. Constant supply of air. 2. Tube containing sponges saturated with ammonia. 3. Tube containing sponges or an asbestos plug saturated with hydrochloric acid. 4. Tube with stopcock bringing the mixed vapours (instead of one, two tubes may be used, bringing the separate vapours) to the reservoir 5. 6. Manometric tube with a small opening through which a jet of ammonium chloride vapour escapes (7). 8. Tube of exit for the mixed air and ammonium chloride vapours. 9. Tube bringing air into the outer manometric tube 6', to keep the jet of vapours 7 at a constant height. 10. Tube connecting the apparatus with the buccal cavity.

to overcome the effects of gravitation and friction, in one set of experiments I used opaque vapours, and in another short columns of water or some lighter fluid.

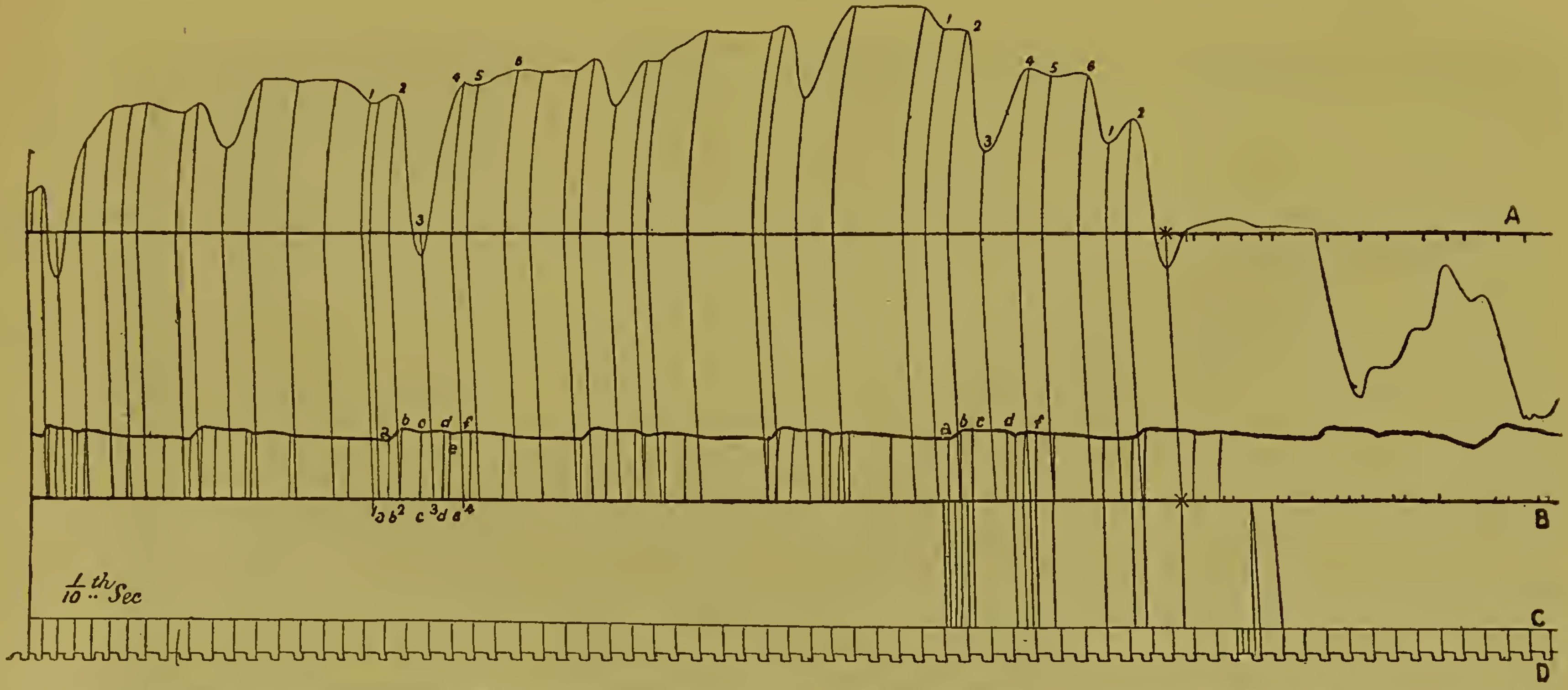

Fig. 5.—A. Line parallel to the abscissæ line drawn at the level of the axis of the recording lever which traced the cardio-pneumatic curve. B. Similar line drawn in connection with the carotid pulse tracing. C. Abscissæ line on which the chronographic as well as the two other curves are projected. This tracing is intended to show the relations of the various parts of the pneumo-cardiographic curve to the various parts of the cardiac revolution. [Allowing a delay of $\frac{1}{10}$th of a second for the transmission of the pulse wave from the basis of the heart to the point where the carotid pulse was taken (the distance between the two being about 0m. 22cm. in the subject experimented upon), the carotid curve can be used to indicate the time of the ventricular systole.]

The most suitable vapours which I could think of were those of chloride of ammonium, which would, I thought, interrupt light almost completely. I therefore constructed an apparatus. I give here a drawing which will explain its nature (Fig. 4). With this I obtained results which did not entirely confirm my expectations. The difficulties arose chiefly from the variability of density of the vapours, and from the tendency they had to form crystalline deposits on the tubes, and to obstruct them. When everything was new and fresh, the apparatus worked very well, but this did not last very long, so that, although theoretically this should be a very perfect form of manometer, since it almost entirely does away with the effects of momentum and friction, yet I have been obliged to abandon it for the present on practical grounds. I will, however, repeat the experiments with heavy-coloured gases, and hope to obtain good results if I can find a sufficiently non-irritating coloured vapour.

III.—Meaning of the Cardio-Pneumatic Curve.

Both from a careful study of the manometric flames, and of the tracings obtained by means of Marey's tambours, I have come to the conclusion that the cardio-pneumatic curve is nearly, though not entirely, the reverse of the ordinary cardiogram. François-Frank,[3] whose investigations I had not noticed till quite lately, and after I had obtained my results, is of opinion that the two curves are exact counterparts of each other. This, I think, is a rather serious error, although it is not so great as that of some others who have imagined that the pulse wave and the cardio-pneumatic impulse were of the same nature. On carefully examining curves which are here reproduced, and which correspond to the cardio-pneumatic impulse and the carotid pulse taken simultaneously with levers of the same length, it is evident that the upper curve is neither parallel to, nor absolutely the reverse of, the lower one.

For the purposes of comparison and discussion it will be convenient to consider the cardio-pneumatic curve as composed of three upstrokes corresponding to expiratory, and three down strokes corresponding to inspiratory, movements of the air. There are, therefore, three apices and three depressions, which I have numbered consecutively 1, 2, 3, 4, 5, and 6 (Fig. 5).

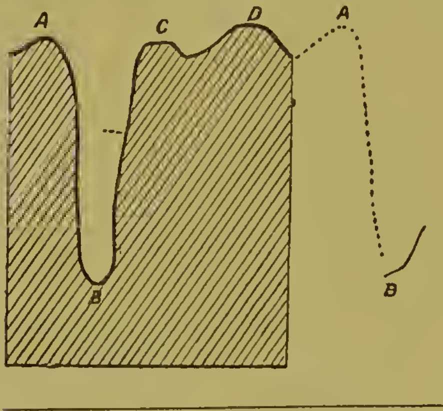

Fig. 5 A.—The length of the levers being taken in account the two curves are projected upon a single line. It is then found that the ventricular systole corresponds to a very slight expansion wave (A) followed immediately by a deep receding wave (B), the lowest part of which is reached a little before the dicrotic wave occurs. A considerable rise (B C) corresponds to the dicrotic wave and is followed by two smaller curves.

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[3] François-Frank in Marey's *Travaux du Laboratoire*, p. 225, 1877; *idem*, p. 319.

In the carotid pulse, which has been obtained simultaneously on the same revolving surface, the elements of the pulse wave are indicated by the letters *a*, *b*, *c*, *d*, *e*, *f*.

a b corresponds to the first part of the ventricular systole and the first sound. *b c* to the second part of the ventricular systole during which the blood is still flowing into the aorta. *c d* to the third part of the ventricular systole, and the successive closure of the aortic and pulmonary semilunar valves. *d e* to the recoil (systole?) of the walls of the arteries which have just been forcibly distended by the ventricular systole. *e f* to the beginning of the dicrotic wave.

By studying these tracings it will be evident, even before making corrections necessary to compensate the retardation of the cardiac impulse during its transit from the heart to the carotid, that the parts marked 1 2 and *a b* closely correspond in the two tracings; 1 precedes *a* by less than $\frac{1}{40}$ of a second, and *b* precedes 2 by about the same amount of time. The great downstroke 2 3 corresponds in part with the interval *b d* in the carotid pulse, and ends before the occurrence of the dicrotic wave. By thus comparing the various segments of the two curves, it is possible to come to the following conclusions:

The small expiratory impulse 1 2 is synchronous with the first part of the ventricular systole (*a b*) in the pulse wave. The large inspiratory impulse 2 3 is synchronous with the greater part of the second and third portions of the ventricular systole, corresponding in the pulse wave with the parts marked *b c d*. The large expiratory movement 3 4 begins a little before or at the time of the second sound, and, therefore, at or just before the beginning of the relaxtion of the ventricles; the dicrotic wave *e f* begins during that ascent of the lever. The apex of that wave corresponds with the end (4) of the expiratory wave.

The rest of the tracings can for the present be left unnoticed.

As this is only a statement of the facts I have observed I will not go more minutely into their explanation at the present time, but will now refer to the observations of Landois and François-Frank, which at first sight seem to be in opposition to my results.

Regarding Landois's curves,[4] I may say that although they resemble more or less François-Frank's and my own curves, the appearance is more apparent than real. Before Landois's curves can be compared they have to be reversed, because owing to the disposition adopted in his apparatus and which differs from that generally in use all the upstrokes correspond to down strokes of other tracings and *vice versâ*. There is another difficulty in understanding the meaning of Landois's results, due to the fact that the explanations given in two parts of the text are contradictory, at any rate apparently so.

The explanations given in small print (text-book)[5] agree fairly with my results, but in order to understand them it is necessary to change the place of one of the numbers of reference in the tracings which accompany the text. Landois has used the sounds of the heart as terms of comparison, but this is not the best way to establish the synchronism of circulatory phenomena, as it introduces serious sources of personal error.

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[4] Landois: *A Textbook of Human Physiology.* Translation by Stirling. First edition, i, p. 110.

[5] English translation by Stirling, first edition.

François-Frank's tracings are similar to mine, but owing to their being very small the correspondence between the parts of the carotid or cardiac pulses and those of the cardio-pneumatic movements is difficult to follow. François-Frank has also entirely overlooked, in comparing the carotid and the cardio-pneumatic curves, the importance of allowing for the difference in the rate of transmission of waves through the air and through the blood. It is true that owing to the size of his tracings such corrections would have been difficult to make.

By means of careful measurements and comparisons of his curves I have, however, been able to find that they are in perfect accordance with my results.

I am, however, obliged to take exception to his interpretation. He thinks that the main inspiratory current is produced by the systole of the ventricle, and is synchronous with it, this view, from what I have said above, and can show in François-Frank's own tracings as well as in my own, is only partly correct.

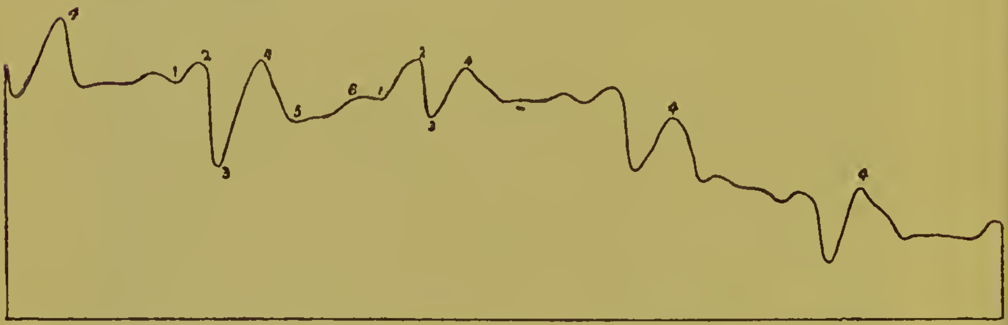

Fig. 6.—Rate of motion 25 mm. per sec. Curve showing the effects of stretching of the lung parenchyma. The tracing was obtained from the same person as the one represented in Fig. 5, the chest wall being expanded as far as possible. The wave (4), corresponding to the dicrotic wave of the pulse, is considerably exaggerated. I have tracings in which this exaggeration is still more marked.

If one wants to realise the full meaning of the cardio-pneumatic movements, a much more minute analysis than that given by this observer is necessary.

I have in the adjoining diagram (Fig. 7) reduced all the tracings to the same scale in order to facilitate their comparison. I may say that although these curves are intentionally diagrammatic, they are based on accurate chronographic measurements, some of which are found in Landois's *Physiology*, and others have been obtained by myself. (In the case of François-Frank's tracings I have obtained the proportions by direct measurements of the curves published by him. I have, unfortunately, not been able to use his cardiographic tracings because of their remarkable want of uniformity, the same event in one curve sometimes preceding, sometimes following, a corresponding point on the other curves ; this is evidently the result of the alteration produced by printing.)

IV. Variations in the Cardio-pneumatic Impulses.

These variations, which form the main object of my research, can be demonstrated best by means of manometric flames, or of the apparatus which is at the present time constructed, and of which, so far, I have only used rough models. By means of Marey's tambours it is also possible to obtain results in a certain number of persons. The chief variations which I have obtained so far are: (1) An exaggeration of the small systolic wave; (2) an exaggeration of the small dia-

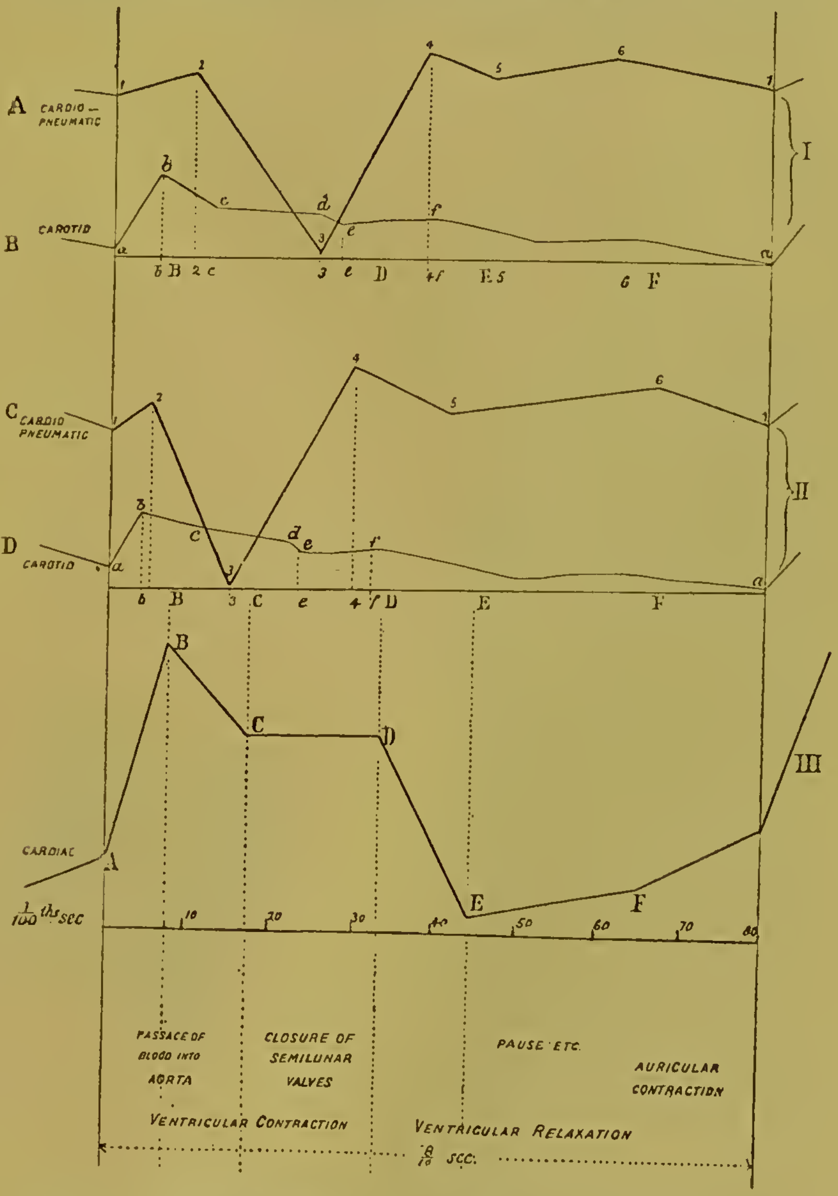

Fig. 7.—I. Cardio-pneumatic and carotid pulses traced simultaneously (S.D.). II. Cardio-pneumatic and carotid pulses traced simultaneously (François-Frank). III. Composite cardiogram based on average measurements (Marey, Landois, Gibson). Diagrams reduced to the same scale to allow comparison. It is, however, important to remember that only A and B in I and also C and D in II are capable of minute comparison. III is only a curve of averages, and gives simply the means of interpreting the other curves. In I and III the curves correspond to chronographic measurements, in II there was no chronographic curve in the original.

stolic wave synchronous with the dicrotic wave (see Fig. 6); (3) an obliteration, more or less complete, of either of these waves; (4) a more or less complete obliteration of the large systolo-diastolic wave. These I have, so far, studied in connection with the degree of stretching and elasticity of the lung tissue in individuals otherwise healthy. I have not, however, collected a sufficient number of data to allow of generalisations being made.